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DEPLOYMENT OPTIONS FOR A SPENT FUEL TREATMENT FACILITY IN THE UNITED STATES

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ABSTRACT

The Department of Energy – Nuclear Energy office is actively pursuing an Advanced Fuel Cycle Initiative (AFCI) to develop spent fuel treatment technologies to enhance the economic attractiveness of advanced nuclear fuel cycles. One alternative being evaluated is to operate a Spent Fuel Treatment facility (SFTF) to recycle spent fuel from light water reactor (LWR) systems. The United States could consider such recycle if there proves to be a significant life cycle cost reduction compared to the once-through direct disposal option. Recycle of spent fuel is the first step to enable a fuel cycle that holds promise to significantly reduce the volume, heat load and long-term radiotoxicity of waste sent to a High Level Waste repository.

INTRODUCTION

Whether to meet the demand for cleaner air, address rising costs of energy resources, supply the growing demand for electricity, support the evolution of a hydrogen economy, or some combination thereof, it appears reasonable that nuclear power will continue to play a vital role in supplying the energy needs of the United States. The US plans to dispose of its spent nuclear fuel in a deep geologic repository located at Yucca Mountain, Nevada. The U.S., as with much of the rest of the world, continues to evaluate the potential to process the spent fuel in a manner that can be beneficial to both energy supply and, perhaps more importantly, repository capacity and performance. Energy demand and energy resources are the subject of numerous studies many of which advocate a renaissance of nuclear energy. Long-term disposal of nuclear waste continues to be a major deterrent to nuclear growth. Given the existing inventory of commercial nuclear spent fuel and the present rate of fuel utilization, additional repository space will be needed in just a few decades. Congress will decide whether this will be at another location, through expansion of the existing location, or perhaps in conjunction with some expanded above ground dry storage.

A promising alternative to direct disposal is to process the commercial spent nuclear fuel into key partitions permitting recovery of some of the energy value while providing vital flexibility to the operation of a repository in a manner to minimize and possibly defer the near-term need for future repositories. It is assumed that such a Spent Fuel Treatment Facility (SFTF) will provide significant benefit to the US nuclear waste program and this paper focuses on key options for deployment of such a facility. The SFTF would partition the spent fuel into manageable components that could be recovered, recycled, or dispositioned as economically beneficial to the overall fuel cycle and/or enhances the repository performance. The goal of the SFTF is to reduce the high level waste volume going to a repository, provide for more effective heat management, enhance the containment performance of the specific waste forms, and provide for energy recovery or transmutation as practical. Operation of a SFTF will enable options for management of plutonium and other minor actinides that do not currently exist and coupled with future Gen IV reactor operations holds promise for reduction of toxicity of materials going to the repository. Other nuclides such as Tc-99 and I-129, which are important to repository performance, can also be processed into waste forms with superior containment properties. The proliferation resistance and containment properties of Pu sent to the repository can be enhanced. The option will also exist to close the fuel cycle recovering energy value as a MOX fuel and/or ultimate destruction of the Pu via transmutation in Gas Cooled Reactors or Fast Reactors of the future.

Obviously, the cost of a SFTF must be justified relative to the overall benefit to and life cycle cost of the total fuel cycle. For purposes of this paper, it is assumed that commercial spent nuclear fuel in the US can be processed in a manner that provides broad cost and utilization benefit to the Nation's deep geologic repository program. Expediting such a facility could enable an impact on Yucca Mountain; however, due to the expected large capital investment and a need based on a modest nuclear growth scenario, timing may be such as to have greatest impact on a second repository. The following discussion addresses deployment options of treatment technologies as related to the capacity of the plant, the rate of generation of the spent fuel, and the overall strategy for queuing spent fuel to the processing plant and waste repository.

Deployment Overview

The recommended deployment strategy is to build a multi-purpose Spent Fuel Treatment Facility (SFTF) to be located on an existing federally-owned site. The location should accommodate not only a standalone spent fuel treatment plant, but also ancillary facilities in support of the broader Advanced Fuel Cycle Initiative (AFCI) program such as Mixed Oxide (MOX) or advanced fuel/transmutation target fabrication facilities. The SFTF would have an initial capacity of 2500 MT/yr, but with an inherent capability to expand its capacity to >3000 MT/yr. Such a SFTF can only be merited in the case where current nuclear power is sustained and the nuclear industry experiences a reasonable growth in the period of 2010 – 2050. A moderate 25-50% growth was assumed as a basis for evaluating facility requirements. A capacity of 2500 MT/Yr appears adequate to meet the needs of such a growth scenario without need for a second such facility for 15-20 yrs. This seems prudent as surely nuclear technology will evolve and a second generation spent fuel facility would surely need to adapt to the economic fuel cycle that will emerge to meet the needs of the future.

The SFTF should be designed in a modular and/or multi-line fashion to support a cost-effective expansion to 3000 MT/yr if desired. The recommended capacity range reflects two major objectives. The first is to process spent fuel that has aged as long as possible (25–30+ years out of the reactor). This opportunity presents itself due to the fact that the US has maintained in-situ storage since the inception of commercial nuclear power. This can enable significant reduction in the life cycle costs of operation [including repository operation]. The second objective is to support a cost-effective capital project to build a SFTF. Evaluations of flat to modest nuclear growth scenarios suggest that a 2500 MT/yr plant can support a 25-year old feed strategy. Capacity much less than 1500 MT/yr, while providing opportunity for much older feed, would rapidly increase the unit cost basis and would not be recommended. World-wide reprocessing experience would suggest that a 2500 MT/yr capacity addressed in a modular or multi-line fashion reflects a reasonable extension of existing technology.

The process envisioned for the SFTF would receive spent fuel shipments from nuclear power sites, or other interim storage areas, and produce products whose value is based upon energy recovery, or direct cost or performance benefit to the national repository program. If economics support, uranium can be recovered with sufficient purity for recycle to enrichment facilities or alternatively disposed as LLW. Plutonium (Pu) and Neptunium (Np) will be recovered and used in the short term as a mixed oxide (MOX) fuel in LWRs or gas-cooled reactors when available. Ultimately the recovered Pu would be consumed in the fast reactors of the future. Alternatively, the Pu can be combined with recovered metals and other nuclides to enhance both its longer term proliferation resistance and repository containment performance. Relatively short-lived fission products such as Cs and Sr would be partitioned into a separate product stream providing a significant cost effective alternative for heat management of these radionuclides at YM or future repositories. Minor actinides such as Am and Cm would be partitioned and the small volume either processed into an enhanced containment waste form or stored for future transmutation in thermal or fast reactor systems. Remaining fission products and the metal cladding wastes would be treated for volume reduction and disposal. The net effect is a much smaller volume of material going to the repository with a significant flexibility and reduction in heat management requirements as well as enhancing the containment performance of the repository. The SFTF would utilize the experience of world-wide commercial spent fuel reprocessing as well as the US experience in both experimental and weapons program reprocessing to establish initial process baselines. The specific design for the SFTF will be the result of technology evolution, demonstration and value engineering.

DEPLOYMENT STRATEGY

The optimum deployment strategy for recycle of commercial spent fuel is one that best meets AFCI program objectives of repository benefit, energy recovery, Pu destruction, and support for the future operation of Generation IV nuclear energy systems. The following strategy topics relate to meeting AFCI program objectives based upon a SFTF operation.

Operational Flexibility

Due to uncertainty surrounding the magnitude of future nuclear power expansion in the U.S. and the inevitable budget constraints, a successful SFTF must offer operational flexibility at a low project capital cost. To achieve these dual objectives, a modular (or multi-line process) concept for a reprocessing facility is recommended. In the modular scenario, the initial reprocessing modules will be built to a process throughput scale consistent with facilities successfully operated in France and the UK (800 – 1000 MT/yr). The reprocessing plant will be located on a site large enough to accommodate a large multi-line (or modular) facility or multiple plants of smaller scale, a [MOX] fuel fabrication facility, ample interim storage area, as well as facilitate transmutation target fabrication (as needed). The advantages of a multiple line plant have been demonstrated by the successful industrial practice by the French at LaHague. For instance, when the two lines are interconnected the plant may continue to operate at half-capacity while significant systems in both lines are undergoing maintenance. To be successful and provide maximum benefit to a repository, a SFTF must be capable of both high yield operation and a high availability to minimize the generation of unique secondary wastes which would have to be package for disposal in a repository. Based on the IAEA data summarized by Prince (1991), a dual-line plant is estimated to cost ~50% more than a single-line plant. Certainly a value based systems engineering approach will used define the design for the SFTF. However, it is believed the multi-line approach would be required to meet the requirements and provide the necessary flexibility in operations.

In the multi-line facility approach, it may be advantageous to build the critical infrastructure but only populate the process equipment for the capacity needed for the shorter term, leaving room for expansion and/or conversion to evolved technology as market conditions or cost-effectiveness warrants. Implementing a phased approach to achieve the ultimate facility capacity permits economies of scale to be achieved in the design, procurement and construction, while minimizing as practical the initial project capital cost. Longer-term project capital requirements can be partially offset by the economic gains realized through reprocessing and electrical generation and the cost avoidance relative to repository operations and deferred need for a second repository.

Siting

The reprocessing facility should be collocated with any planned fuel/target fabrication facility to take advantage of cost, safety and security advantages of shared services, infrastructure, and operating staff. Additional efficiencies can be gained by siting the SFTF on an existing federal site in conjunction with ancillary facilities and to take advantage of existing operations, storage capability, and other macro-infrastructure as applicable. The factors of integrated transportation and required interim storage will require significant consideration relative to the cost impact on the processing of the spent fuel as well as distribution of the various SFTF and related MOX products. While siting involves many factors (many of which are not technology based), there are two obvious geographic locations to consider. A location at or near the repository site may provide opportunity to utilize shared interim storage space and minimize transport of HLW to the repository from the SFTF. Under such a Yucca Mountain scenario, a co-located fuel fabrication plant would then have to transport the MOX fuel and the recovered uranium across the country to where most of the nuclear reactors and current enrichment facilities are located. A SFTF with a relative Eastern location would be in closer proximity to the reactor and enrichment end-users, but must address the cost of shipping the processed HLW to YM for disposition, albeit at a much smaller volume.

Functional Collaboration (with Repository and/or Fuel Fabrication facilities)

Due to the massive scale of the facilities and large number of personnel required to operate them, significant cost avoidances can be realized by sharing of common infrastructure including consideration of integrated processing within common structures. Close coupling of processes also permit the flexibility to reduce interim storage requirements and minimize any duplication of process functionality between the facilities. Such strategies have the potential to reduce both capital and life cycle costs especially relative to safeguards and security requirements, control strategy, interim storage, licensing/permitting, waste operations, transportation, basic balance of plant facilities including complex laboratories, and required functions such as emergency response, etc.

Spent Fuel Feed Strategy

Both Yucca Mountain and the SFTF share a common objective to utilize the spent fuel in a manner that minimizes operating cost and capital expenditure. Both facilities can benefit from handling “well-aged” spent fuel (25-30+ years since reactor discharge), while facing the necessity of blending a range of aged fuels for consistency in heat management, design application and/or processing. Aged fuel has much less high energy radiation and presents opportunity for simpler design, lower cost and less waste relative to SFTF operations. Therefore a common strategy for co-operation of the SFTF and on-going repository operations would have to be developed such that both spent fuel feed to the SFTF and “waste” to YM are well defined with appropriate schedules developed. Regardless of long range planning, it will be desirable to begin the first few years of SFTF operations using very old feed such that any necessary process revisions and or recovery operations can be completed without excessive exposure or remote operations.

Nuclear Industry involvement

Participation and acceptance of program objectives are important to the overall successful implementation of the AFCI program. The nuclear power industry will be challenged with two main issues for which acceptable alternatives and/or incentives will be necessary. To utilize a strategy of “well-aged” feed requires that a substantial inventory of spent fuel be maintained. This creates a challenge to consider continued in-situ storage at the utility locations and/or new storage to be defined and located. From a nuclear industry basis, there is a desire to remove spent fuel from the utility location to either make room for fresh discharge or to support site closure activities. For a SFTF, it would be desirable to minimize the size of the interim storage to provide an appropriate blend of feed. In any case the logistics of interim storage and transportation hold opportunity for significant cost avoidance but take cooperative planning and policy/regulations by the nuclear industry, OCRWM, AFCI program personnel as well as Congressional interaction. The second issue is that of developing a significant MOX market to utilize the recovered Pu from the SFTF if that is the desired route for Pu utilization. The nuclear industry must become willing participants having weighed risks and benefits to develop a viable market (e.g., 30+ LWRs using MOX and consideration for new GCRs to use a full Pu core or new LWRs to use a full MOX core). This will surely invoke significant resistance and stockholder concerns. A major program that defines risk and proactively addresses the major public relations concerns will have to be developed with involvement of the major stakeholders.

Project considerations (schedule, budget, technical feasibility)

The Yucca Mountain Repository currently has a goal to begin operation in 2010. Thus the YM must license the facility based upon a baseline operation that appropriately does not consider a SFTF operation. If a SFTF can prove to be of significant benefit to the repository operation, then design and construction of the SFT should begin as soon as practical such that YM can consider more cost effective operations based upon actual performance of a SFTF. While schemes could be envisioned to temporarily place the oldest spent fuel in YM with plans for short term retrieval as part of an overall SFTF feed strategy, the most cost-effective approach would likely be to minimize the placement of untreated spent fuel in YM. Processing spent fuel before the "waste" is sent for final disposition in the repository maximizes both the volume and heat management benefits resulting from the operation.

Product end-use Considerations

Decisions relative to "product" end-use such as recycle of uranium vs. waste, use of Pu for fuel value vs. waste, and enhanced containment waste forms will drive the selection of applied technologies for the SFTF. Although major production scale reprocessing facilities exist in foreign countries, a U.S. plan to separate Pu and Np as well as the minor actinides (Am, Cm) for re-use in reactor systems drives the need to consider several processing alternatives. Project alternatives such as phased capacity installation and co-process/collocation considerations with MOX can minimize initial construction capital outlay while locking-in the economies of scale relative to building and infrastructure cost. Such decisions on end-use including flexibility to change direction based upon economics and technology evolution will dictate the overall scope of the facility.

CONCLUSION

The SFTF will be a key element to the DOE's AFCI mission to develop and implement spent fuel treatment technologies that enhance the performance of the high level waste repository and reduce the cost of geological disposal. A successful SFTF operation will depend upon cooperation between civilian and government agencies as well as with private industry with emphasis on effective collaboration between SFTF, repository authorities and the nuclear industry. Public recognition and acceptance is needed of the coupling between the AFCI and Gen IV Nuclear Energy programs as enabling an expanded role for nuclear power as a sustainable resource that will address long-term U.S. energy security, environmental and economic concerns.

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